COMPARISON BETWEEN FRICTIONAL BEHAVIOR OF THE SOFT AND BRITTLE MATERIALS AT DIFFERENT CONTACT PRESSURES

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ABSTRACT

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Coefficient of friction changed significantly by the change in contact pressure. Experimental measurement of the coefficient of friction in different contact pressures can be useful in numerical and analytical analysis of many engineering problems, such as metal forming process. This study dedicated to investigate the sensitivity of the friction coefficient to changes in contact pressures. To aim this goal the special tribometer device has been fabricated and the coefficient of friction of the soft and brittle metals when sliding with a low speed on a rigid body are measured for different contact pressures. The friction sensitivity of the soft (copper and aluminum) and brittle (steel) samples to changes in contact pressure are compared and discussed. The results showed that both brittle and soft metals are highly sensitive for change in contact pressure but their behaviour is slightly different. While the coefficient of friction of the steel sample when sliding on a steel substrate is reduced sharply by a little increase in contact pressure; the coefficient of friction of the soft material when sliding on a steel substrate is reduced slowly depending on the magnetude of the applied normal load.

Keywords: Coefficient of Friction, Metal Forming, Severe Plastic Deformation, Experiment

INTRODUCTION

Friction is not a material property; but it is a characteristic of a system including base and sliding materials, surface treatment and working conditions (Boyd and Robertson 1945). It is proved that the friction coefficient is considerably influenced by temperature, sliding velocity, normal pressure, surface roughness, etc (Ulutan, Celik et al. 2010, Yamaguchi, Ando et al. 2011, Pearson, Shipway et al. 2013). Generally, friction coefficient of a pair of materials at low contact pressures is considerably different than the friction coefficient at very high

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contact pressures (Xu 2003, Jiménez, Bielsa et al. 2007). Despite, there are few researches dedicated to find a friction coefficient via simulation (Patil, Chakkingal et al. 2008), experimental methods are still the only reliable way for measuring friction coefficient values. Indeed, friction coefficient is critical in order to calculate a required force for the forming of materials and also achieving accurate results from modeling using numerical methods (Keum, Wagoner et al. 2004). Severe plastic deformation (SPD) is a special process which involves very high contact pressures (about the several order of the sample's yield strength) (Eskandarzade, Masoumi et al.) and greatly influenced by the friction.. Researchers are looking for the way to reduce the friction between the sample and die to pull down the required ram forces (Mehdi Eskandarzade 2016). However the problem is challenging and it is not possible to reduce the friction in high contact pressures just by using lubricants or even employing ultrasonic vibrations (Djavanroodi, Ahmadian et al. 2013). It realy needs basic study of the friction mechanism at different contact conditions. The main aim of this study is to compare the friction mechanisms for brittle-brittle and soft-brittle systems. For many material pairs there are no reliable friction coefficient values at very high contact pressures in litreture. Then, the secondary goal of the investigation is to provide experimental data of friction coefficient for some material pairs in different contact pressures which can be useful in metal forming studies. In last years, researchers have developed a friction test apparatus for measuring a friction coefficient between sheet metals in a crash test (Lai, Xia et al. 2012). They have designed their device to use in measuring of friction coefficient values at a relatively high contact pressures (up to 100 MPa). However, this amount of pressure is still too low with respect to pressures which are involved in some metal forming methods like a severe plastic deformation (SPD) process. Recently, Pougis *et al.* have suggested a suitable means for measuring friction coefficient values at very high contact pressures and low speeds *(Pougis, Philippon et al. 2013)*. A few shortcomings of his suggested tribometer have been also corrected in this study. In current study the friction coefficient for copper-steel and Aluminum-steel system will be measured for different contact pressures up to 700MPa using an apparatus suggested by researchers (Pougis, Philippon et al. 2013). The experimental friction coefficient measurements which will be offered through with figures are useful to compare frictional behavior of materials and also to find a precise friction coefficient of material pairs in different contact pressures.

EXPERIMENTAL SETUP

The main mechanism of the experimental setup for measuring coefficient of friction (COF) in different contact pressures is very similar to that one reported in reference (Pougis, Philippon et al. 2013). Figure 1 shows the schematic of the experimental setup of this study. In addition, Figure 2 indicates the experimental setup which includes a tribometer and a tension test machine. A tribometer consists of the main body, Mandrel, two jaws and a load cell for measuring an applied force. Material type of jaws is chosen as the real SPD die's material type. Jaws were from hardened steel. The Mandrel holds a sample and moves it between two jaws. In order to guarantee that only sample tips will be in contact with jaws' surface, the specimen length is prepared about 0.1 millimeter longer than the Mandrel wide length on each side (Figure 3). By tightening a screw, it is possible to create compression stress at the specimen between two jaws and inside a Mandrel. A whole system is attached to a tensile test machine as shown in Figure 2. In fact, the plunger of the tensile test machine is connected to the Mandrel of the tribometer. An indicator shows an applied load in a load cell and a specimen. After setting a desired applied hydrostatic load on a specimen by fastening a screw and checking the load at the indicator, the plunger of a tensile test machine moves the specimen down on a jaws face. Displacement speed of the plunger can be controlled via computer. Also, the load and displacement values of the plunger are recorded by an electronic data acquisition system which is available on a machine.

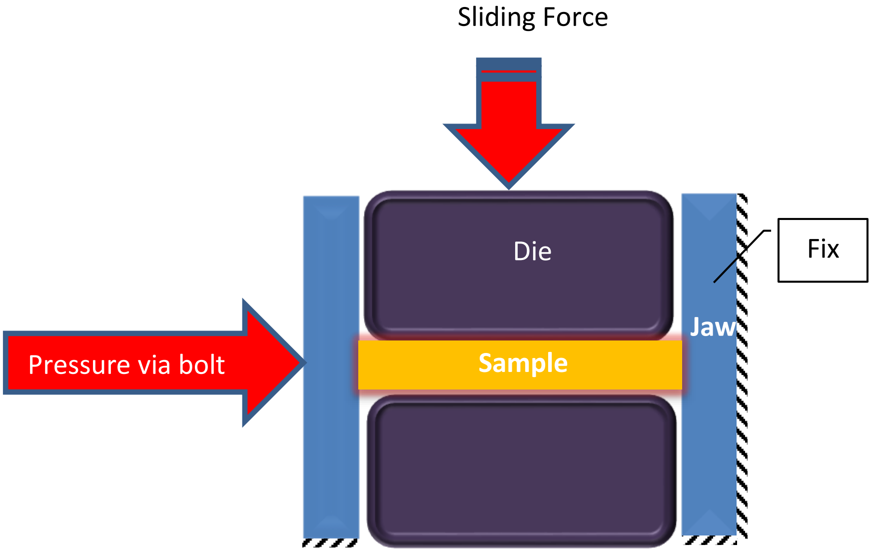

Figure 1. Schematic of friction measuring system.

This system is a new arrangement of a friction test apparatus which already offered by other investigators (Pougis, Philippon et al. 2013). However, the current design has three differences with the tribometer offered in reference. Firstly, here load cell is used in order to measure the applied force that is easier and mostly more precise than strain gauges on connecting screws. Secondly, at the reference tribometer, two guide rods hardly can assure the parallelism of the jaws, especially due to the sample tips motion. Therefore here, four guide rods are used to constrain the Jaw's in all directions except sliding direction. And finally, the mechanism of applied force changed here, whereas now it is possible to apply load by turning just one nut instead of two nuts in the design of a reference.

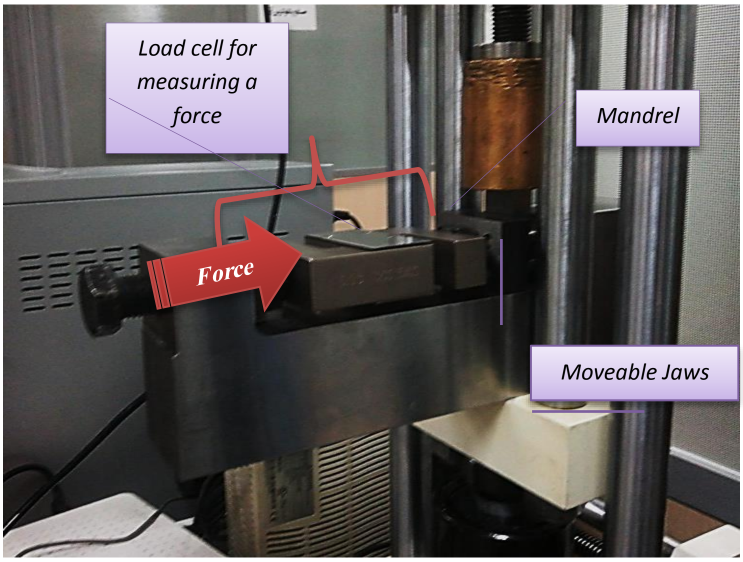

Figure 2. The tribometer used in this study.

Experimental Procedure for measuring COF

Jaws were made from AISI 4340 steel (with yield strength of 710 MPa). Their surface was hardened to about 60 Rockwell C. Specimens were made from 7075 aluminum alloy and technically pure copper. Specimens had 15.2 mm length and 8mm diameter. Special care has been taken in order to ensure the parallelism of the sample tips using special fixtures. In addition, two sets of specimens were prepared for copper and Aluminum materials. Specimens are located in a Mandrel hole with transition fit. After the Mandrel with a sample inside of it, is moved to the center point of the Jaws, the moveable jaws is fastened by turning a screw. The sample is fully confined inside the Mandrel and then, by fastening a screw it is produced a hydrostatic pressure on a sample which is followed by a very low speed motion. In order to study the effect of normal pressure on a friction coefficient, an applied force adjusted in a way that to squeeze the specimen with 50, 100, 200, 300, 400, 500, 600 and 700 MPa normal pressures for different test samples. A total sliding of the samples was 1 mm for all tests that is done with a tangential rate of 1 mm per minute (which is close to normal velocities in SPD process). The recorded data was displacement of a specimen on a Jaw's face and a required force for this sliding. The corresponding COF will be calculated based on this information in next sections. Whole test was accomplished for both copper and Aluminum Alloy samples.

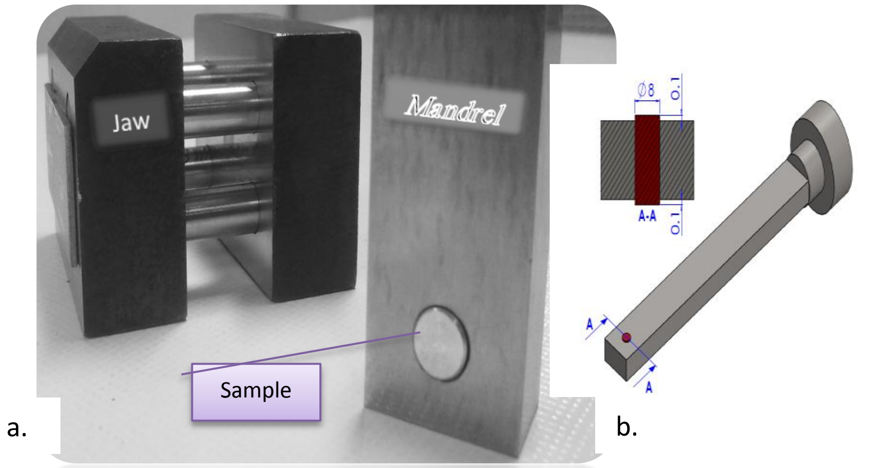

Figure 3. (a) a photo of Jaws, Mandrel and a sample, (b) schematic of the Mandrel and a sample on it.

RESULTS AND DISCUSSION

Figure 4 shows sample force-displacement curves of the experimental tests for Aluminum Alloy samples. In order to check the repeatability of the results, all tests are repeated for twice. Stick-slip phenomena were dominant during all tests. This fact can also be understood from saw type force-displacement curves (Figure. 4). During a friction test, a drop of the apparent normal pressure was observed. It was varied from 3% to 10% for different normal pressures that was readable from load cell indicator. Tests are performed under displacement controlled loading conditions. As it can be found from Figure 3, force-displacement curves consists of two distinguished stages: in the first stage the sample still resists against sliding and the reported displacements (by increasing force) is related to the elastic deformation of the system (test machine and asperities). This stage can be assumed linear. The second stage can be referred to the sliding of the sample on Jaws' face. This stage starts just after the tangential force overcomes static frictional resistance of the system. This point can be used to calculate the static friction coefficient of the system using Eq. 1. In this equation, μ stands for a friction coefficient, F_T , is a tangential force and F_N , shows normal force. It should be noted that the factor 2 in Eq. 1 is due to the presence of two sliding surfaces.

$$\mu = \frac{F_T}{2F_N} \qquad (1)$$

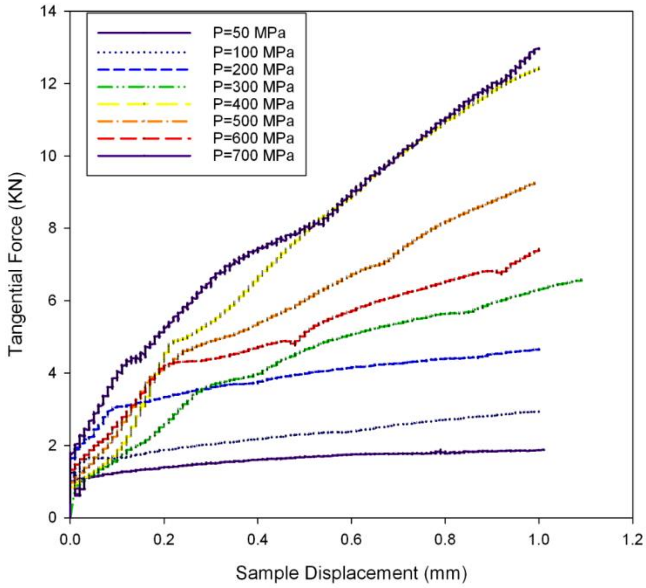

Figure 4. Shows sample displacement versus tangential force for Al-Alloy samples when sliding on steel Jaws.

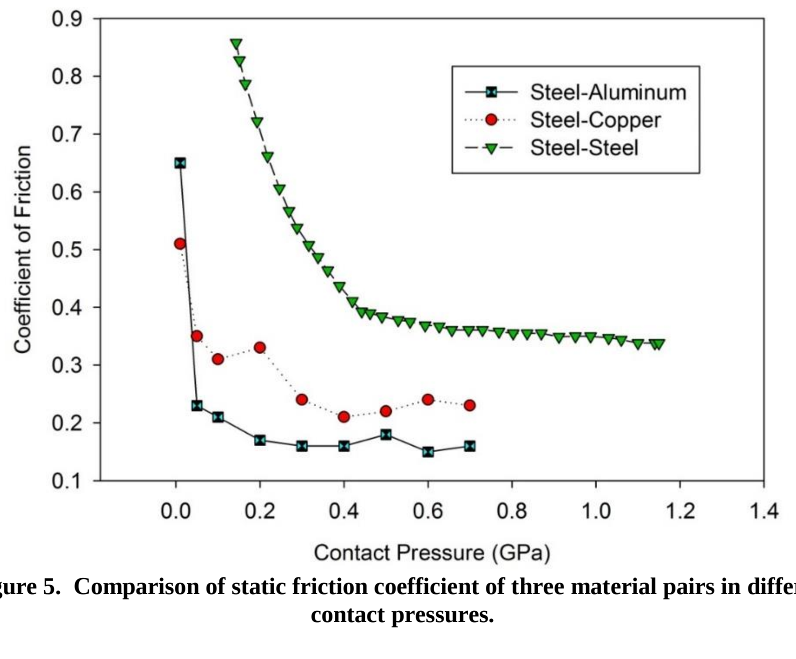

Figure 5. Comparison of static friction coefficient of three material pairs in different contact pressures.

Figure 5 illustrates the results for COF calculations using Eq. 1 for copper-steel and Aluminum alloy-steel system at different contact pressures. In addition, for comparison reasons, the COF values for the steel-steel system is included in Figure 5 from reference (Pougis, Philippon et al. 2013).

According to Fig. 5 all material pairs have similar trends and all of them shows about 60-70% reduction in static coefficient of friction when the contact pressure changes from about zero to about 0.8 GPa. However, as it is clear from Fig. 5 the frictional behaviors of the soft materials (Aluminum alloy and pure copper), when sliding on a steel substrate, are different than the frictional behavior of the brittle material (steel). While the coefficient of friction of the steel sample when sliding on a steel substrate reduces exponentially, depending on the magnetude of the applied normal load; the coefficient of friction of the soft materials reduces suddenly due to the little increase in contact pressure; . In addition, the value of COF for both soft materials is about 0.2 for the pressures higher than 300 MPa regardless of their material type; which is considerably less than the COF for brittle-brittle system (steel-steel) in similar contact pressures with about 0.35 for COF in the flat section of the curve.

CONCLUSION

Friction coefficients of copper-steel and aluminum-steel system at different contact pressures for dry sliding condition have been measured using a revised version of friction test apparatus presented in literature. Experimental curves offered in this study for the coefficient of friction versus contact pressure of three different material pairs can be useful in numerical analysis of metal forming process, especially severe plastic deformation methods. Comparison of the experimental results for frictional behavior of soft-brittle and brittle-brittle material systems revealed that both systems are very sensitivity for variation in contact pressures. However, unlike the brittle-brittle contact system, the COF of the soft-brittle systems reduces suddenly by increasing in contact pressure. This is where the COF of the brittle-brittle system reduces exponentially by increasing a contact pressure to about 70MPa and remains constant at 0.35 for higher contact pressures.

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